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## A FULLY AUTOMATIC SATELLITE DATA PROCESSOR

*by Frank A. Keipert, Richard C. Lee, and Fred B. Cox*

*Goddard Space Flight Center*

*Greenbelt, Md.*

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## ABSTRACT

The "Satellite Telemetry Automatic Reduction System" (STARS II), is a fully automatic computer controlled telemetry data processor. Each system incorporates a CDC 3200 computer as its central element, together with facilities for converting and processing telemetry data and ground station time inputs, plus a full complement of simulation equipments. The objectives of STARS II are to maximize data recovery, reduce turn-around time, increase flexibility, and improve operational efficiency. These systems encompass advanced techniques for computer controlled data processing of high-volume telemetry data.

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## INTRODUCTION

The Satellite Telemetry Automatic Reduction Systems (STARS) project (Reference 1) is part of an overall plan to develop an optimum system for handling and processing high-volume satellite telemetry data. These objectives of the STARS project are being successfully accomplished by the STARS I (Reference 2) and STARS II systems.

The STARS I system has been utilized in processing PCM and PFM data from numerous scientific satellites. This system is based on digitization of data to produce a digital tape in proper format for entry into a computer. These equipments are manually set up and are limited in total capability. Furthermore, an additional pass through a computer is required to quality check and edit the satellite data for further analysis.

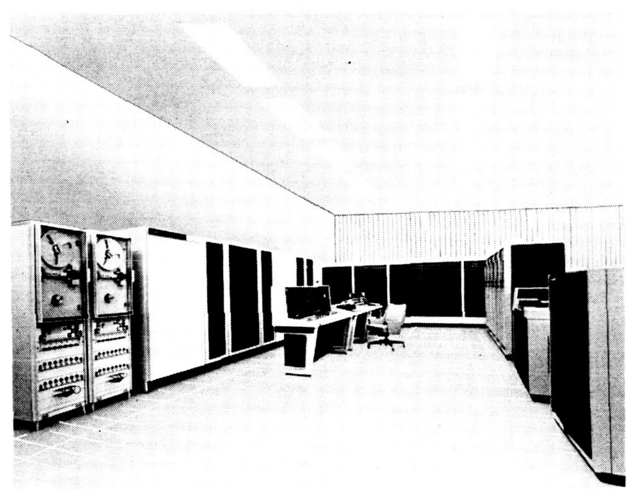

Figure 1—STARS II system.

Faced with a rapidly increasing volume of data, NASA developed the concept of a highly automatic, computer-controlled, high-speed data processing system. The objectives of this concept, embodied in the STARS II program, are to increase the efficiency and economy of operation of the data processing equipment, to enhance its capability, and to minimize the elapsed time from acquisition to delivery to experimenters. The two major characteristics of the STARS II equipment are use of an automatic system and performance of signal processing and quality checking in a single integrated system. Two STARS II systems have been produced on contract by Beckman Instruments, Incorporated. Each system (Figure 1) incorporates a Control Data Corporation 3200 computer as its central control element.

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## SYSTEM DESCRIPTION

The STARS II systems encompass advanced concepts in computer controlled processing of high-volume telemetry data and employ state-of-the-art signal conditioning, computing, and peripheral input-output devices. Especially significant is the fact that special software has been developed for the automatic setup, checkout, and diagnostic operations.

A STARS II system includes facilities for converting and processing two PCM data and three ground station time inputs, plus a full complement of computer-controlled simulation equipments and analog magnetic tape units. Each system is fully automatic, including computer control of the simulation equipment to permit automatic system setup, checkout, and diagnostic operations. Total or partial manual control may also be exercised from a central operation and maintenance console.

The primary inputs to the STARS II system are analog magnetic tapes recorded by the worldwide network of satellite tracking stations. These tapes contain both telemetry data received during a satellite pass over a station and time signals generated at the station, and they may be processed at playback speeds from 1/8 to 32 times real time. Inputs from a real time data link and a local time encoder may also be received and processed.

The primary STARS II system output is a computer master tape containing all telemetry data as well as time and quality information generated during the run. This tape will, in general, be further processed on other computing equipment. However, the STARS II systems are of adequate capacity to perform auxiliary functions such as scaling, conversion, and sorting, either with single or multiple-pass operations.

## ORGANIZATION

The STARS II system is organized to

1. Decrease the amount of reprocessing time required.
2. Eliminate the need for producing intermediate digital tapes between signal processing and quality checking operations.
3. Reduce setup time and operator errors.
4. Reduce turn-around time.
5. Maximize data recovery.
6. Increase flexibility.
7. Simplify checkout and maintenance.

Integration of the computer with the signal processing equipment decreases the amount of reprocessing by on-line monitoring of system performance and data quality. Substandard system performance is immediately detected so that corrective action may be initiated. The direct input from the signal processing equipment to the computer eliminates a digital tape and the attendant logistic handling. Full computer control of the system reduces the setup time for each run and minimizes operator errors, and automatic verification of the setup assures system readiness. These features, combined with the capability to process data tapes faster than they were recorded, significantly reduce turn-around time.

The fully automatic setup and computer control also improves data recovery. The computer can dynamically control the data acquisition strategy and adapt to format changes. In addition, the computer provides a capability to handle any data format: a special mode of operation performs only bit detection in the PCM subsystem and all group synchronization in the computer.

System checkout is simplified through the use of an automatic, computer controlled simulator, which is operated in a closed loop manner with the computer for rapid setup and verification of series of diagnostic tests. In addition, a central maintenance console provides displays and manual controls for each subsystem. An oscilloscope monitor on this console allows manual selection of critical signals for display. As soon as a malfunction is localized to a particular subsystem, it may be disconnected electronically for off-line maintenance.

A major goal has been efficient production operation. To avoid system idle time while tapes are being rewound, two analog tape units are provided for alternate playback of input tapes. The same approach may be used for the computer output tapes. For system setup, the different satellite formats are contained on a library tape and may be readily accessed by means of a control card. During a processing run, continuous indication of the system performance and data quality is available on a high speed printer. In addition, performance statistics and job accounting information are stored on a separate digital tape. At the end of the run, identification cards are punched to accompany the output tapes.

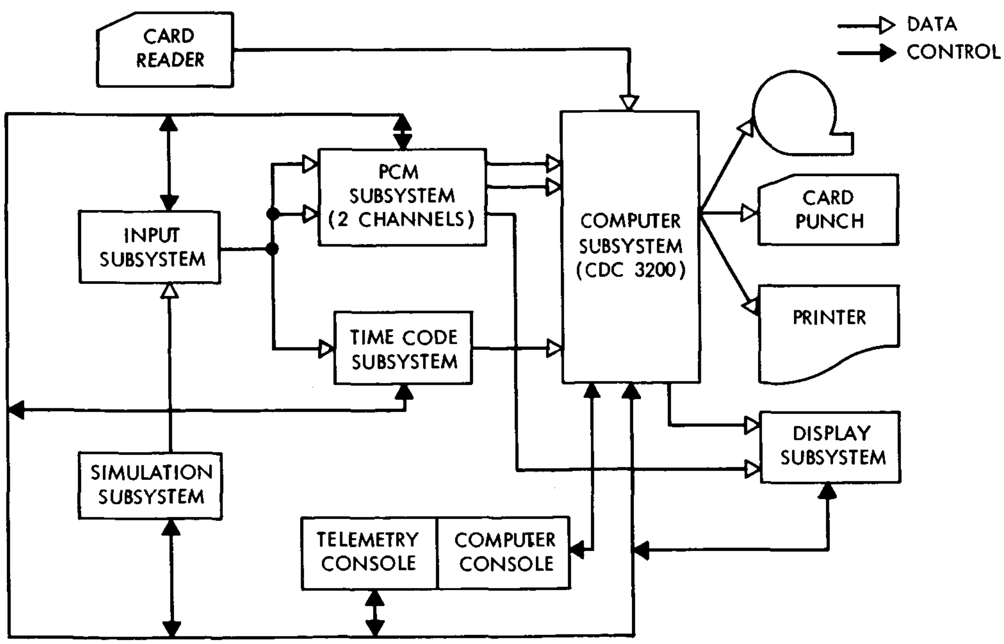


Figure 2—STARS II block diagram.

Figure 2 shows the functional organization of the STARS II system. The CDC 3200 general-purpose computer is the basic control element for the complement of signal conditioning, conversion, control, simulation and computer peripheral equipments. This computer may be used to perform both on- and off-line functions. It is provided with 16,384 words of memory, magnetic tapes, card equipment, and a high-speed line printer.

## SUBSYSTEMS

In this section are described the design and operation of the major subsystems, excluding the computer, of the STARS II system.

### Input Subsystem

The input subsystem consists of analog magnetic tape units, input control, and attenuation circuits for perturbing local time encoder. The two analog tape units are seven-speed, electrically switchable machines which will play back at speeds from 1-7/8 to 120 inches per second. The speed and motion may be controlled either automatically by the computer or manually from the central console or tape unit. Equalizers are automatically switched as a function of tape speed selection.

From the two 7-track analog tape transports, a real-time data link, or simulator, the input control selects inputs to one or both of the PCM subsystem channels. The input source may be selected either from the computer or from the console. Provision is made for automatic tape track switching between two preselected data tracks on the same tape input. Time code signals are routed from the appropriate source to the time code translator when the various PCM sources are selected.

For control of source selection, setup words are transmitted to the input control, where they are held in storage and decoded to drive the appropriate control relays. In addition to the control contacts, each relay has a set of status-contacts which are used by the computer to verify the setup.

The input control also contains attenuation circuits which permit computer selection of the time code signal levels received from a local NASA time code generator. These facilities are used during computer diagnostic operations to check the time code subsystem under varying degrees of signal amplitude degradation.

The stored-program PCM simulator is also an input, and this unit may be selected as a data source by either one or both data channels in the PCM subsystem. Selection of the simulator as input to the PCM primary (bit) synchronizers is accomplished by the input control. The simulator also generates digital outputs which may be inserted directly into the secondary (group) synchronizers, bypassing the primary synchronizer. This input mode is normally used in diagnostics or in program checkout when it is desired to bypass the primary synchronizer. The regenerated serial output of each primary synchronizer is fed back directly to the simulator to permit the detection of bit errors during a simulation operation.

## PCM Subsystem

Each STARS II system contains two separate channels which may simultaneously process a PCM data stream. PCM Channel A contains a stored-program controller operating under "static" and "dynamic" control of programs contained in a magnetic core memory. A static instruction is used once per processing run for the automatic setup of such items as bit rate, data acquisition strategy, and format parameters. Dynamic instructions are those used at least once for every telemetry word, for variable word length control, data routing to displays, subframe synchronizations, and limit checking. Channel B is a simplified unit which contains no magnetic core memory controller; however, it may be set up from a program stored in the memory of the first channel. This dual-channel processing capability is provided to permit one-pass processing of data from satellites that transmit over two radio frequency links.

### *PCM Channel A*

This unit contains primary and secondary synchronization elements and a stored-program control element, which includes a special arithmetic unit, for performing limit check operations on the received data. During setup and processing, operation is controlled by a program stored in a magnetic core memory. Hardware facilities were provided for word, frame and subframe synchronization acquisition. The primary program loading source is the computer, which may also read back the contents of the PCM subsystem memory for verification.

A block diagram of PCM Channel A is shown in Figure 3. The PCM bit synchronizer provides recovery of the data bits and clock from the received input. For high recovery of data, both point-sampling and integrate-and-dump detectors are provided in the signal conditioners. Ambiguity detection for split phase codes and automatic polarity inversion capability are also provided. For greater reliability in processing data from single channel satellites, the two bit synchronizers are switchable between the two PCM subsystems.

Serial data are entered into the secondary synchronizer, where they are reformatted into parallel words for computer entry. This formatting includes word-by-word control from the memory of the number of bits per word and for the consistent justification of data received with either MSB (Most Significant Bit) or LSB (Least Significant Bit) first transmission. Data are always LSB-justified for computer entry, and MSB-justified for limit checks and for output to the display subsystem.

Satellites may transmit telemetry data as collected data or from on-board tape recorders. These recorders may be played back in either the forward or reverse direction. The STARS II system can reverse the bit sequence of each word as well as the word sequence of each file. In the latter case, the purpose would be to re-order the data. Information rates of 512,000 bits per second in split phase or NRZ (Non-Return to Zero) rates in excess of 1,000,000 bits per second may be handled, at instantaneous word rates of up to 250,000 words per second.

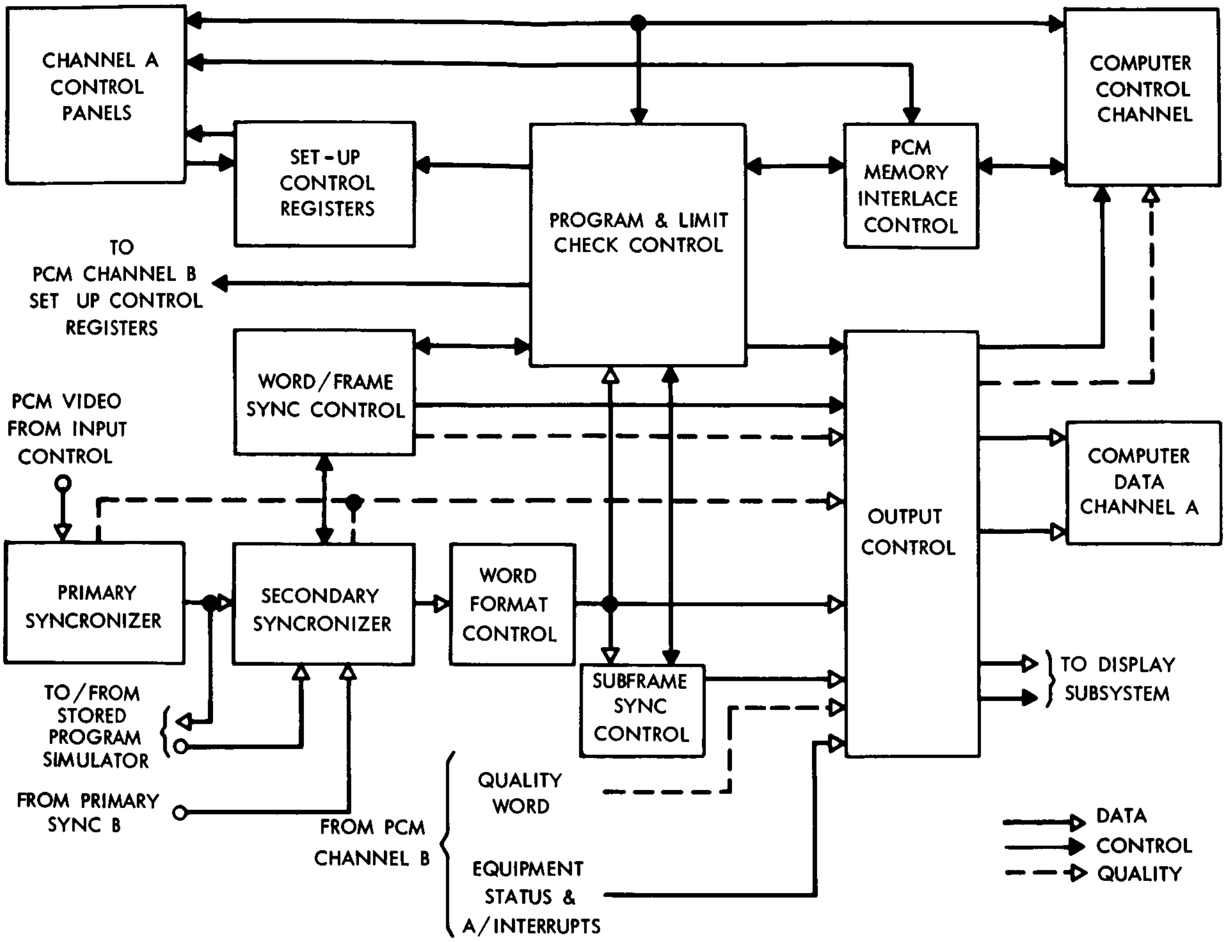


Figure 3—PCM Channel A.

The secondary synchronizer contains a 32-bit correlator for recognition of word and frame synchronization patterns. Fixed or alternating complement frame synchronization codes may be handled. A three-mode frame synchronization strategy with "search," "verify" and "lock" is used. For high data recovery, data transfer to the computer may be started in either the verify or the lock mode. If it is started in the verify mode, the information may be saved in the computer for use in case the PCM subsystem proceeds into lock mode. Automatic correction for multiple bit slippage for high data recovery is another capability provided.

The word/frame synchronization control produces word and frame synchronization quality indications for entry into the computer on a frame basis.

The subframe synchronization control contains facilities for synchronizing two randomly-phased subcommutator sequences. The start of these sequences may be identified by fixed code patterns appearing in adjacent or split main frame channels, a frame synchronization pattern which complements at the end of each subframe, or a binary count contained in a data channel which identifies each frame. Subframe synchronization patterns, stored in the program memory, are read out at the expected time of occurrence within the data. The subcommutator correlator produces error counts which are used to acquire proper phasing of the subcommutation sequences.

Data words may be limit checked and flagged by the arithmetic unit contained in the PCM program control unit. Four types of limit checks may be performed: high limit check, low limit check, zero order high/low check, and first-order (derivative) high/low check.

The entire subsystem is controlled by programs stored in the memory. Up to seven independent programs may be stored. The memory capacity is 4096 twenty-four-bit words with a full read/restore cycle time of 2 microseconds. It may be loaded from either the CDC 3200 computer or a keyboard on the central console. The contents of any or all memory cells may be read out for verification either automatically by the computer or manually. An interlock permits these load/unload operations to be performed on a non-interference basis while data are being processed.

Data are entered into the computer by means of a separate input/output channel. A double-rank data buffer insures adequate time for computer reinitialization of the input/output channel between frames. Data are entered in 12-bit bytes, and 12- to 24-bit assembly may be performed by the computer input/output channel if desired. Input data words longer than 12 bits are automatically disassembled into 12-bit or smaller increments by the subsystem. Variable word length control is exercised by stored commands in the PCM subsystem memory. Selected data channels may also be routed to the display subsystem under control of the stored program.

A bit-stream mode of data input is provided to handle formats that are beyond the PCM subsystem capability. In this mode, reconditioned bits are transferred to the computer, regardless of word, frame, or subframe synchronization; then frame synchronization and formatting are accomplished in the computer. Although this is not an efficient mode of operation, in certain cases, such as the burst-frame operation, it is the only known method of reliably recovering the data.

Data quality information assembled from the various elements in the subsystem is sampled at the end of each frame and is available to the computer on request, via a separate I/0 channel. Normally, this information, which includes bit, word, frame, and subframe synchronization, and quality flags, is entered on a frame basis, along with time, by the control channel. A binary count of the number of errors which exist in the frame synchronization pattern is also generated and entered as part of the quality information. This permits the computer to tabulate the errors directly on a frame basis and therefore to estimate the bit error rate.

*PCM Channel B*

PCM Channel B is a second processing unit that operates independently of Channel A, but which may be set up under control of any one of seven static programs contained in the memory of Channel A.

A block diagram of PCM Channel B is shown in Figure 4. The basic unit, consisting of the primary synchronizer, the secondary synchronizer, and the word/frame synchronization control,

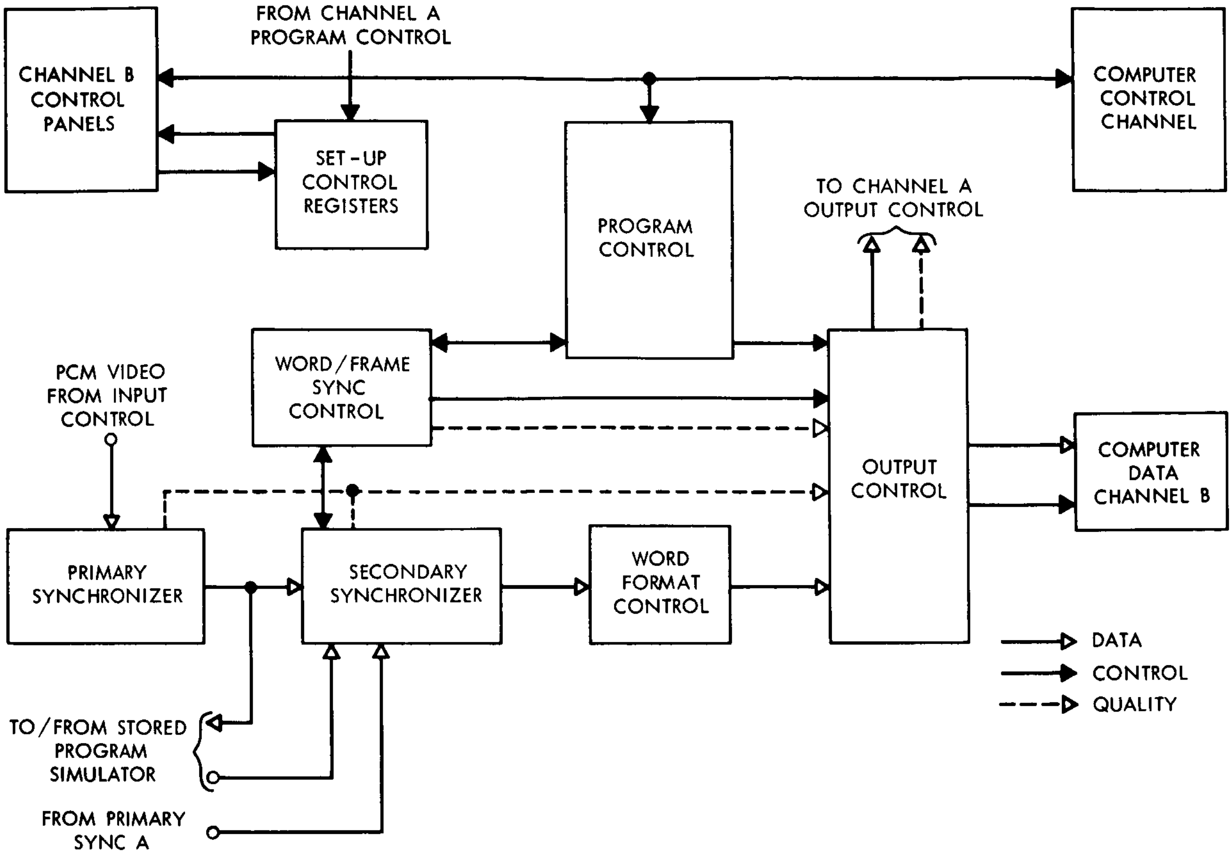


Figure 4—PCM Channel B.

is identical to that of PCM Channel A. Channel B does not have the capability for variable word length, limit checking, subframe synchronization, and routing of data to the display subsystem. If any of these operations are required, they may be added to the computer processing program for Channel B.

Data are entered into the computer by a separate input/output channel. A double-rank buffer register is also used, since Channel B can process input words faster than Channel A. Quality flags are available to the computer at the end of each frame via the same input/output channel used for PCM Channel A control.

## Time-Code Subsystem

The time-code subsystem (Figure 5) is a fully automatic system providing computer setup of speedup factor, input signal selection, and strategy for the best estimate of time. The time code signals, NASA Binary Coded Decimal (BCD) and Serial Decimal (SD), are fed to the time decoding unit, where synchronization is acquired and the codes are detected. A reference frequency is used to increment a time accumulator, whose output is converted to binary milliseconds-of-day and day-of-year and transferred into an accumulating register. This register is incremented by

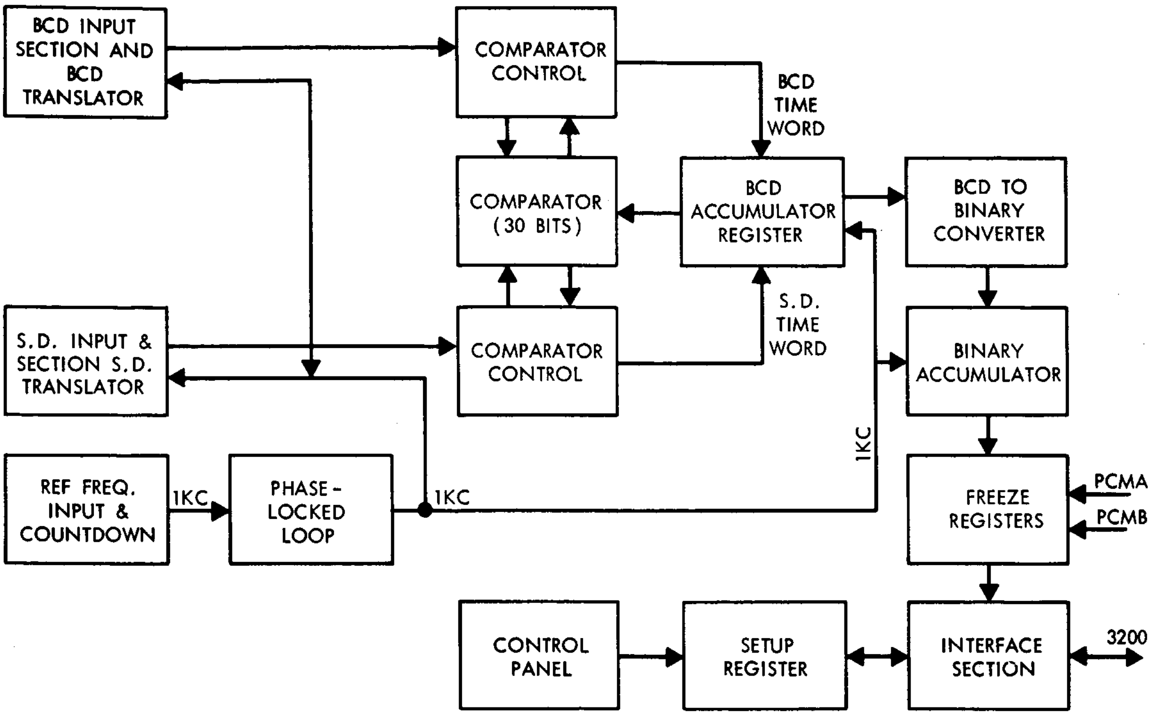


Figure 5—Time-code subsystem.

millisecond pulses, and is the source from which the computer receives its time words on request. Three separate time signals are received and used to derive a best estimate of true time values. Internal quality checking and error detection in the time code translators insure that the contents of the accumulator is a best estimate of the received time. Separate buffer registers are included to store time words associated with the two PCM channels.

Inputs accepted by the time code translators from either magnetic tape or from a direct source include the NASA BCD time code and the SD time code in the form of a DC level shift or a modulated 1 kc carrier. The reference frequency channel accepts a reference frequency of either 1 kc, 10 kc, or 100 kc. The time code translator operates from 50 cycles to 100 kc—a range encompassing the 1/8 to 32 times playback ratio of the time codes.

The two time code inputs are filtered, buffered through automatic gain control (AGC) amplifiers, and routed to two separate time code translators, which provide parallel time information to separate output registers. "Flags" indicate a decrease of signal level below a predetermined threshold. Bandpass filters used for the 1 kc BCD carrier are selectable by either automatic or manual control to accommodate the various playback ratios.

The reference frequency or the carrier of either time code phase-locks a voltage-controlled oscillator, which is used to flywheel over dropouts due to noise and loss of signal. A flag indicates dropout of the reference frequency signal level.

The outputs of the two time code translator registers are routed to a comparator, where they are both compared to a counting BCD accumulator for validity of time information. This comparator control determines which of the two registers' contents will be transferred to the BCD accumulator register. The accumulator's output is routed to a BCD-to-binary converter, which converts the time-of-year information into binary form. Status flags are generated indicating the quality of the received time codes, and this information is processed by the computer to establish the confidence levels.

Two buffer registers permit both of the processing elements to sample the time words which are correlated with each PCM data frame. This technique is used because delays in computer time sampling could introduce errors of several milliseconds at high tape playback ratios.

## Display Subsystem

The display subsystem provides facilities for generating analog outputs which may be recorded on a 6-channel oscillograph. This capability may be expanded to sixteen channels. Such outputs may be derived directly from the computer or from the PCM subsystem, where routing designators are generated by the stored program in Channel A. Moreover, these separate inputs to the display subsystem may be obtained concurrently, permitting both raw and computer processed data to be simultaneously displayed. A 1 pps time strobe signal is available from the time code subsystem for recording timing marks on the output recording.

The display subsystem may be controlled either by the computer or manually. A PCM lockout switch is provided to inhibit inputs from the PCM subsystem while the oscillograph is being used solely for computer outputs.

## Simulation Subsystem

The stored program simulator (Figure 6), which functions as an integral part of the overall STARS II system, provides the flexibility required to generate data formats needed to properly test the PCM subsystem. The computer provides added flexibility in that all control functions, including such parameters as signal rate, code type, and signal-to-noise ratios, may be set up or altered automatically. Thus, a thorough test of the overall system may be made without operator intervention.

The simulator functions, which may be controlled automatically from the computer or manually from the central console, include

1. Signal amplitude, offset, and polarity.
2. Information rate.
3. Code format and modulation type.
4. MSB/LSB first.
5. Signal blanking.

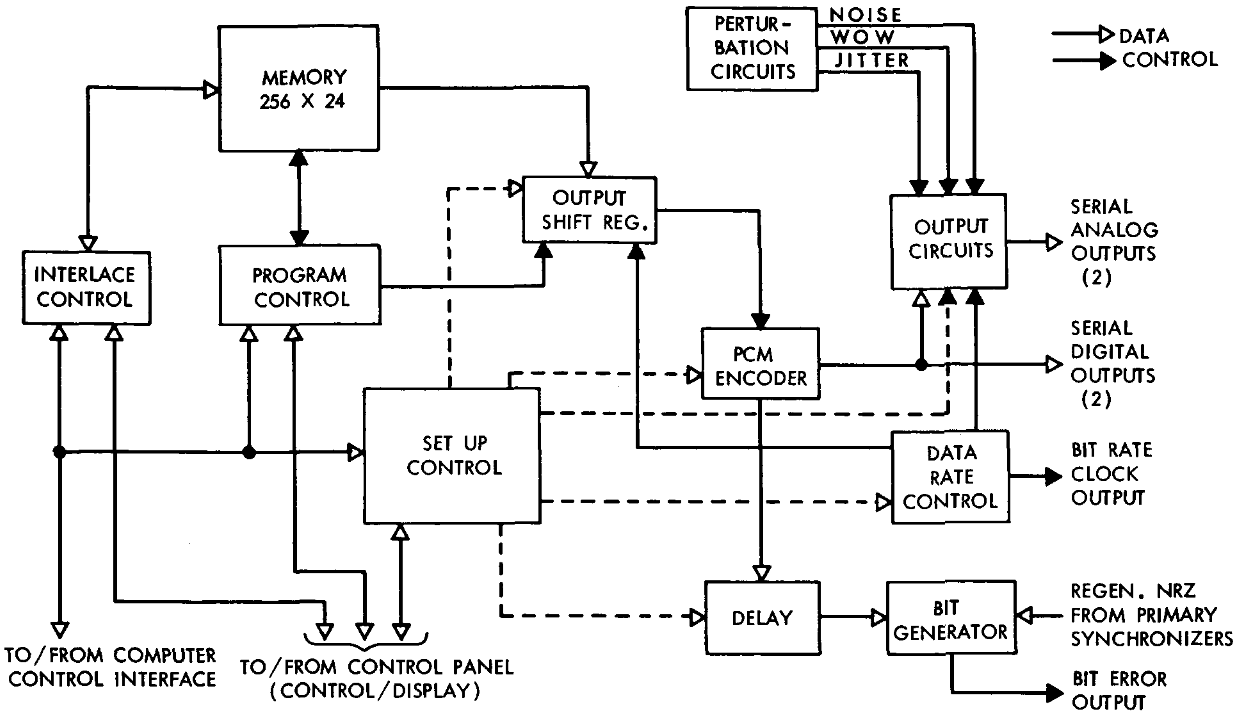


Figure 6—PCM simulator.

6. Signal-to-noise ratio.
7. Signal bandwidth and noise bandwidth.
8. Bit rate jitter.
9. RUN/STOP.
10. Contents of memory and program starting location.

The normal simulator serial output, which may be perturbed by noise sources in the simulator, is routed to the PCM primary synchronizers via the input subsystem. Then the conditioned serial output of the primary synchronizer is fed back to the simulator for comparison with the original data. A noise-free digital output is also generated by the simulator, and may be selected as a test input for the PCM secondary synchronizers, thus bypassing the primary synchronizer.

The simulator is organized around a 256-word-by-24-bit, 5-microsecond magnetic core memory containing the instructions which control the program execution sequence and the generation of data words. Each data-generating instruction produces a word of 12 bits or less, which is converted to serial PCM by the encoder. The output is applied to the output mixers, where the gain, offset, filtering, and signal perturbation are adjusted to the desired levels. Signal perturbations which may be introduced include Gaussian noise, baseline wow, signal rate jitter, and signal blanking.

Regardless of whether or not the program is running, any location in the magnetic core memory may be addressed by the computer or the console for reading or writing a word. Thus, dynamic program changes may be made during simulation operations.

### Telemetry Console

In addition to the standard computer console, a central telemetry console is provided, accommodating maintenance controls for all telemetry subsystems. From this central location, the operator may continuously monitor signal waveforms and the operating status of the telemetry subsystems, and may manually override any or all functions normally set up by the computer.

This console is divided into functional sections corresponding to the major elements of the system. The subsystem maintenance panels contain manual overrides for all of the system's automatic controls, as well as indications of the state of the control functions. Interlocks protect against accidental operator intervention during automatic operation.

A centralized oscilloscope monitor selects and displays critical analog signals on the console. The signals to be monitored and their associated external trigger inputs are routed to the oscilloscope via five twelve-position selector switches. One switch is for external triggering, and the other four are for signal inputs to a four-trace oscilloscope, thus providing a multitude of signal and trigger combinations.

## SYSTEM SOFTWARE

The system software consists of special job-oriented programs under control of the CDC 3200 Executive program SCOPE. The following system programs are available:

1. SCOPE: Standard CDC operating executive. All STARS II programs operate under overall control of this routine.
2. TELTRAN: Telemetry Symbolic Translator provided as an assembly programming language for the stored-program PCM and simulation subsystems. The structure of the programs closely resembles the respective telemetry formats. This technique represents a simplification over normal computer programs. Symbolic PCM subsystem and simulator programs are input from either cards or tape. A binary object program output is generated on either cards or tape, or may be transferred directly to the telemetry subsystem. Symbolic and binary assembly listings are also provided on the line printer.
3. TELLOAD: Telemetry Loader provided to control the transfer of binary object programs from cards or tape into the memory of the PCM subsystem and simulator.
4. DEXEC: Diagnostic Executive Loader provided to call the main executive (MAIN) into memory from the program tape.
5. MAIN: Main executive which accepts control inputs from either cards or the console typewriter, locates the selected routine from the program tape, and controls its execution.
6. SETUP: System setup program which controls the loading of hardware setup registers in the telemetry subsystems. This program also reads back the results of the setup to verify that it has been properly performed.

7. BEEP: Elementary Executive Program which provides direct communication between the PCM Subsystem and the computer console typewriter.

8. DIAGNOSTIC ROUTINES: Individual diagnostic routines provided to exercise the telemetry subsystems in their various modes of operation.

9. COMET: An executive program which provides full system setup, job sequencing, and calculation of statistics concerning system performance, will be available in the near future.

## OPERATING MODES

The STARS II system may be operated in three basic modes: on-line, diagnostic, and off-line. In the on-line mode, the computer operates in conjunction with the telemetry signal input and conversion equipments. In the diagnostic mode, the computer utilizes the simulation equipments in conjunction with the telemetry subsystems to detect and isolate faulty operation of the system hardware; this same mode is also used for checkout of programs. In the off-line mode, the computer operates as an independent general-purpose computing unit.

### On-Line Mode

During on-line operation, the primary data path is from the input subsystem to a digital output tape via the computer and one or both of the PCM subsystem channels. During this data recovery function, time code inputs are also processed, and the best estimate of time is produced by the time code subsystem. Concurrently, information about the quality of the received data and time signal inputs is assembled by the individual subsystem. The time and quality inputs are entered into the computer on a frame basis, refined by internal computer routines, merged in the memory with the data, and subsequently recorded on the output tape. Data may be processed by the system at speeds from 1/8 to 32 times the telemetry data rate. Since the satellite transmission rates are fixed, this speedup capability reduces the processing time proportionally.

Auxiliary functions such as data scaling, linearizing, sorting, etc., can be performed concurrently by the computer. The amount of auxiliary computing performed will depend on the input data rates and the number of required operations for a single pass. Auxiliary outputs, such as printer listings or oscillograph recordings, may be produced at the same time. On-line processing, including initial setup, is fully automatic under computer control. The process may be monitored at all times by the operator, and any necessary manual overrides can be exercised from the central maintenance console.

### Diagnostic Mode

The STARS II system is designed to make full use of automated diagnostic test and maintenance operations. These test operations are broken down into two broad categories: hardware test and maintenance, and checkout of programs. A third test function combines these functions in end-to-end operational readiness and calibration tests performed immediately before and perhaps after a run to verify system status.

The first category requires that the system hardware be exercised sufficiently to confirm proper circuit operation: special simulation formats derive the hardware elements through the necessary modes to detect and isolate hardware malfunctions.

The second category requires capability for simulation of complex formats to duplicate the inputs to be received from the satellites. The simulated inputs are generated at the expected playback rates to verify that the programs are properly timed. The stored program simulator provides the capability for generating all test formats necessary for both PCM hardware diagnostic and program tests. In addition, a NASA time code generator is available for diagnostic operations on the time code equipment.

Checkout of programs is an important phase of the STARS system test. In general, both the computer and the PCM subsystem programs must be checked out under conditions which duplicate those expected as nearly as possible. Three programs are required: the computer program, the PCM system program, and the simulator program. During initial program checkout phases, the primary or bit synchronizers may be bypassed and the simulation output entered directly into the secondary or group synchronizer. This permits the program logic to be checked on errorless data or on data with controlled errors inserted at desired points in the simulation. In the final checkout phase, using the primary synchronizers, various noise perturbations may be added to the simulated data to check the quality assessment operations of the program under actual conditions.

### Off-Line Mode

In the off-line mode, the computer may be operated as a general-purpose machine, independent of the external processing and conversion elements. Aside from routine computational functions, the computer may be used for assembly of CDC 3200 programs and the associated PCM subsystem programs using the TELTRAN assembly routine.

## SYSTEM PERFORMANCE

The value of the STARS II system depends primarily on the amount of data that can be successfully processed per unit of time. Many factors, such as system checkout and maintenance, setup time, operator actions, and reprocessing, influence this amount and have already been discussed. For processing large volumes of data, the system throughput rate represents a major factor, which may be expressed as the number of telemetry data bits per second that can be processed in a one pass operation. Processing is limited by the input/output speed of the STARS II System and the capability to perform all necessary hardware and software operations during the pass. The input speed limitations are determined by the maximum playback rate of the analog tape unit, the speedup capability of the system, the PCM primary synchronizer, and the maximum word rate of the PCM processing equipment.

All the telemetry data, with time and quality information, must be recorded on a single output digital tape for further processing. The output rate is therefore limited by the digital tape capability. The maximum average character rate of the digital tape unit is

$$R_0 = s \cdot d \cdot e \quad \text{characters per second,} \tag{1}$$

where

$s$ = tape speed in inches per second,

$d$ = recording density in characters per inch,

$e$ = efficiency of tape usage.

For the maximum rate, there are no stops between records. The output rate of the computer as a function of the telemetry input can be expressed as

$$R_0 = \frac{r \cdot b}{w}\left(1 + \frac{a}{100}\right)\left\lceil\frac{w}{6}\right\rceil \quad \text{characters per second,} \tag{2}$$

where

$r$ = speedup ratio,

$b$ = recording information rate in bits per second,

$w$ = telemetry word length,

$a$ = percentage of quality and time characters per frame,

$\lceil x \rceil$ = smallest integer greater than $x$.

The efficiency of tape usage may also be expressed in terms of the telemetry format parameters:

$$e = \frac{\frac{n \cdot f}{d}\left(1 + \frac{a}{100}\right)\left\lceil\frac{w}{6}\right\rceil}{\frac{3}{4} + \frac{n \cdot f}{d}\left(1 + \frac{a}{100}\right)\left\lceil\frac{w}{6}\right\rceil}, \tag{3}$$

where

$n$ = number of frames per tape record,

$f$ = telemetry frame length in telemetry words.

The following restrictions to the parameters are imposed by the system

$$r \cdot b \leq 512 \times 10^3 \text{ bits per second},$$

$$\frac{r \cdot b}{w} \leq 250 \times 10^3 \text{ words per second},$$

$$d = 200,\ 556,\ \text{or } 800 \text{ characters per inch},$$

$$r = 1/8,\ 1/4,\ 1/2,\ 1,\ 2,\ 4,\ 8,\ 16,\ \text{or } 32,$$

$$1\text{-}7/8 \leq v \cdot r \leq 120,$$

where

$v$ = recording speed of the analog tape in inches per second.

By combining Equations 1, 2, and 3, the largest possible speedup ratio is

$$r \leq \frac{s \cdot d \cdot n \cdot f \cdot w}{\left(\frac{3d}{4} + n \cdot f\left(1 + \frac{a}{100}\right)\left\lceil\frac{w}{6}\right\rceil\right) \cdot b} .$$

The output tape from the STARS II system is fed to a large scale digital computer for data decommutation. The general program designed for this process requires that the data in the computer memory be arranged in a matrix corresponding to a telemetry subcommutator sequence. The data will be stored on the output tape in variable record lengths with a selected maximum number of frames per record. Loss of frame synchronization or subcommutator slippage will cause record termination. In the worst case, one frame will be written in a record. If this is due to loss of frame synchronization, no telemetry data will be processed during this interval and the system throughout will not be affected. However, in the case of subcommutator slippage, a continuous telemetry data stream may have to be written in single frame records. This requires a calculation of $r$ with $n = 1$, and therefore a possible reduction in speedup ratio.

Once the maximum speedup ratio is determined by the input and output capability, the available number of instructions per frame for processing may be expressed as

$$P_f = \frac{f \cdot w \cdot 10^6}{2 \cdot t \cdot r \cdot b} - f$$

where

$t$ = memory cycle time in microseconds.

If the number of instructions required to process a frame of data exceeds the number available, the speedup ratio must be reduced. In this case, the system will be process limited.

The system capability will now be illustrated by a specific case. Consider the following conditions:

s = 150 inches per second,

d = 800 characters per inch,

f = 128 words per frame,

w = 9 bits per word,

b = 64,000 bits per second,

a = 5.5 percent,

t = 1.25 microseconds,

n = 8 frames per record.

For this set of conditions, r must be less than or equal to 6.25. Therefore, a speedup of 4 may be selected. The number of instructions available for processing each frame would be 1672.

## CONCLUSIONS

The PCM STARS II system is in operation. The design goal of a fully automatic system capable of handling any PCM telemetry format has been achieved. This system improves on previous data processing methods by reducing tape handling, setup time, operator errors, and turn-around time. Furthermore, high data recovery and system flexibility are provided. The system capacity is available for such operations as limit checking, calibrating, and smoothing, in addition to quality checking and editing operations. With these capabilities, the STARS II systems represent a significant advancement in the art of processing high-volume telemetry data.

Goddard Space Flight Center
National Aeronautics and Space Administration
Greenbelt, Maryland, December 30, 1966
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